Title: The role of South American grazing lands in mitigating greenhouse gas emissions. A reply to: "Reassessing the role of grazing lands in carbon-balance estimations: Meta-analysis and review", by Viglizzo et al., (2019).

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Introduction

The paper by Viglizzo *et al.* (2019) "**Reassessing the role of grazing lands in carbon-balance estimations: Meta-analysis and review**" proposed a new methodology to assess changes in soil organic carbon (SOC) stock associated with land use, and applied it to four countries of South America: Argentina, Brazil, Paraguay, and Uruguay, all members of the MERCOSUR trade bloc. One finding of their assessment was that grazing lands are currently accumulating SOC at rates high enough to"*... generate C surpluses that could not only offset rural emissions, but could also partially or totally offset the emissions of non-rural sectors*". Understandably, these results raised interest among local farmers and stakeholders, because they could have enormous implications for the design and implementation of national policies, in particular the Nationally Determined Contributions (NDCs) to the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC), as well as actions related to building competitive advantages in international markets.

Viglizzo *et al.* (2019) builds on the premise that the grazing lands of the MERCOSUR region are not in a steady state, and therefore their SOC stocks are not in equilibrium. Without further testing this hypothesis, they propose a new method to estimate changes in SOC stocks (“revised method”), as an alternative to the simplified, but widely accepted IPCC Tier 1 method (IPCC, 2006, 2019). This new “revised method”, presented again in Ricard and Viglizzo (2020), is based on two complementary approaches: (i) a new equation that estimates SOC formation from belowground carbon inputs (named the “Theoretical assessment”), and (ii) a worldwide literature review of SOC shifts following different land use changes (named the “Empirical assessment”). Although we agree that grazing lands may not be at equilibrium, we found two major flaws in their manuscript that overestimate the potential SOC sequestration in grazing lands and, thus, in our view invalidate their main conclusions.

First major flaw: the equation used in the "Theoretical assessment" does not adequately estimate SOC changes

The new equation proposed by Viglizzo *et al.* (2019) states that SOC stock change (S_{SOC}) can be estimated from the annual growth of belowground biomass (BGB) minus carbon losses from BGB through respiration before being converted into SOC (see equation in Fig. 1a, extracted from Viglizzo *et al.*, 2019). In our view, this equation includes two conceptual errors:

First, the equation is incomplete because it does not account for carbon losses due to respiration of existing SOC (i.e. SOC mineralization, flux i in Fig. 1b), nor aboveground biomass (AGB) inputs to the soil (flux d in Fig. 1b). Admittedly, AGB inputs are less efficient than BGB to form SOC (Jackson *et al.*, 2017; Sokol and Bradford, 2019) but nevertheless cannot be neglected. However, it is the absence of SOC mineralization what in our view largely invalidates the equation. Omitting such term in the equation makes the theoretical assessment fall into a major conceptual error, since it implies that once the SOC is formed, it remains and accumulates indefinitely over time. We believe this is the reason why carbon sequestration rates estimated by Viglizzo *et al*., (2019) are overestimated.

Second, carbon losses from BGB due to heterotrophic respiration (flux j in Fig. 1b) are misinterpreted as root turnover estimates. The authors state that the term "L" in the equation (Fig. 1a) represents "*the loss of carbon from BGB due to respiration under different thermal conditions before being converted into SOC*" (Viglizzo *et al*., 2019). However, "L" was in their case estimated on the base of root turnover data from Gill and Jackson (2000), who defined it as the proportion of the maximum stock of roots that is annually replaced by new roots. Therefore, by subtracting "L" to the term (AGBg * BGB/AGB * 0.47) which represents the annual root growth, the equation is actually estimating the mass of BGB that stays as BGB from one year to the next. Undoubtedly, the equation in Fig. 1a does not adequately estimate SOC changes.

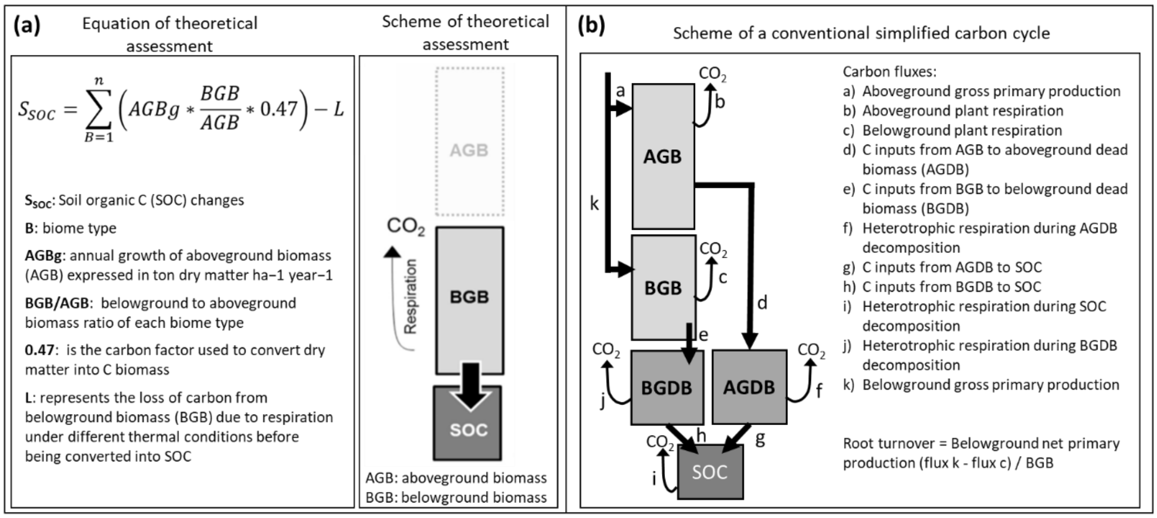

Fig. 1. Theorical assessment proposed by Viglizzo *et al*., (2019) to estimate SOC stock changes (a) and a simplified conceptual model of the carbon cycle in terrestrial ecosystems, showing carbon fluxes (black arrows) among atmosphere, vegetation and soils (b).

Second major flaw: the "Empirical assessment" incorrectly extrapolates SOC change rates of land use transitions to steady land uses

In the "Empirical assessment", annual data on SOC stock changes under several ecological transitions were gathered from the global literature. Based on this data, a meta-analysis was carried out to test the hypothesis that *"…C gain exceeds C loss in grazing lands that are managed at low livestock densities*" (Viglizzo *et al.*, 2019). Studies were grouped under different climate regions and classified as forests, croplands or grazing lands (i.e. grasslands & savannas, shrublands, and cultivated pastures) based on the last land use described in each study, regardless its initial condition (see Table S3 of Viglizzo *et al.*, 2019). Then, SOC changes in the MERCOSUR region were estimated by multiplying the averaged annual SOC change per each land use and climate zone by its total area in the region. This approach has three major issues:

First, the hypothesis could not be tested with this methodology because reviewed data are for ecological transitions while the hypothesis refers to grazing lands that are continuously managed at low livestock densities. Second, there is no indication that the ecological transitions gathered in the literature review would accurately represents the average current ecological transitions in the MERCOSUR, and the large area of unchanged land cover (most relevant to the hypothesis) does not seem to be represented in the estimation. Third, SOC accumulation rates for each land use of the MERCOSUR region were attributed without any reference to the elapsed time. The importance of soil as a carbon sink in the first years after changes in land use or soil management is well recognized in the literature (Stockmann *et al.*, 2013). However, equally well known is the fact that carbon accumulation is time-limited and this should be considered in any analysis involving carbon balance (Smith, 2014; Godde *et al.*, 2020). There is no evidence that all MERCOSUR lands are in the initial phases of ecological transitions with positive carbon balances, when SOC accumulation could be expected.

Other concerns

In addition to the two above-mentioned major flaws, the paper raises a large list of concerns, such as:

(i) The meta-analysis is not accompanied by the description of search criteria nor statistical procedures, making replicates or updates impossible. Calculations did not consider differences in soil depths (which varied between 0.03 and 1.2 m, and in several cases were not reported), the level of data aggregation (average *versus* independent sites according to the study), nor the deviation of the averages, as required by standard meta-analysis practice.

(ii) It remains unclear why some values of particular studies were included in the meta-analysis, while others of the same study were left out (such as Falesi, 1976; Veldkamp, 1994; Neil *et al*., 1997; Marchao *et al*., 2009; Boddey *et al*., 2010; Eclesia *et al*., 2012; Qin *et al*., 2015, reported in Table S3 of supplementary material in Viglizzo *et al*., 2019). Several of the excluded values correspond to sites reporting SOC losses, resulting in a bias toward positive values in SOC changes (e.g., Neils *et al*. [1997] where site 9 was excluded or Eclesia *et al*. [2012] where two negative values were also excluded from the analysis).

(iii) In Table S3 of the supplementary material some data were included repeatedly in different categories (e.g. data for "tropical intact" and "regrowth" from Pan *et al*. [2011] is repeated in “all tropical” category); two values for the "Perennial pastures Canada" category (0.97 and 1.22) are referenced from Stockmann *et al*. [2013], but apparently were not reported in this paper; we could not find values for the "Cultivated pastures Canada" category in Bolinder *et al*. [2002]; for several studies, reported ranges were incorrectly considered as two independent values (e.g., Conant and Paustian, 2002; Zhang *et al*., 2008; Boddey *et al*., 2010; Chambers *et al*., 2016).

(iv) The regression analysis in Fig. 4 of Viglizzo *et al*. (2019) includes a spurious correlation between the “Empirical” and “Theoretical assessments” by including the size of each biome as multiplier in both axes. A comparison of SOC stocks per unit of area would be a much better measure. In addition, the units included in the figure are mistaken because it is not possible that these high values refer to one hectare per year, they more likely are *per biome* and per year. Similar errors are observed throughout the manuscript, such as in Table 1, where the land under grazing in Uruguay is larger than the country total area, or in Fig. 3 where geographical distribution of several land use categories disagree with well-known patterns in the region (e.g., Baeza and Paruelo, 2020).

(v) Viglizzo *et al*. (2019) incorrectly state: "*While IPCC Tier 1 attributes forest lands a significant potential for C sequestration, it assumes that C gains and losses of biomass in grazing lands are close to zero*". What IPCC actually assumes for Tier 1 is that the difference between gains and losses is close to zero in grasslands, forests, and all other land use categories as long as there is no significant land use change or changes in disturbance regimes. This steady state assumption for SOC stocks is widely accepted by the scientific community, as shown by synthesis papers (Poeplau *et al*., 2011) and long-term experiments (Smith, 2014).

(vi) The putative SOC gains in MERCOSUR grazing lands are justified by Viglizzo *et al*. (2019) on the basis of low livestock densities. It is important to note that their estimated low average (0.46 heads ha^{-1}) results from averaging large areas of low productivity and very low stocking-rates like Patagonia, but several local reviews suggest that stocking rates in the region are around their ecological maximum or even higher (Oesterheld *et al*., 1998, Oliva *et al*., 2012; de Faccio Carvalho & Batello, 2012). Despite this, livestock densities are not used in the “Theoretical assessment” calculations, and most articles reviewed for the “Empirical assessment” are not focused on livestock densities but on ecological transitions.

(vii) We questioned the methods used to estimate GHG emissions. The EDGAR database is often used as a coarse estimate for GHG emissions from the land sector, typically at the continental scale. This approach can be justified when there is paucity of data, but only if the comparisons are of the same sort, e.g. emissions from different continents. In the case of the MERCOSUR region, there is scarce empirical data on land GHG emissions in general, and from the livestock sector in particular.

Conclusions

We conclude that the major flaws described above, in addition to the other listed concerns, invalidate the C sequestration rates estimated by Viglizzo *et al.* (2019). Thus, their main conclusion that C accrual in grassland soils can offset greenhouse gas emissions from rural plus non-rural sectors of MERCOSUR region is not valid. We agree with them in that IPCC Tier 1 methodologies for national inventories in the region have shortcomings, including that some grazing lands are probably not in steady state. However, we argue that the proposed revised method does not improve our understanding of carbon balances.

Livestock production in the region, mostly free-range grazing on pastures and natural grasslands, has many environmental benefits and provides outstanding ecosystem services to rural and urban populations, contributing to water cycling, erosion and flood control, and even preserving biodiversity (in comparison to croplands). There is a clear need to improve the empirical base for this sort of assessments, which will lead to better climate change mitigation policies for our common Earth.

References

Baeza, S., Paruelo, J.M., 2020. Land Use/Land Cover Change (2000–2014) in the Rio de la Plata Grasslands: An Analysis Based on MODIS NDVI Time Series. Remote Sensing 12, 381.

de Faccio Carvalho, P.C., Batello, C., 2009. Access to land, livestock production and ecosystem conservation in the Brazilian Campos biome: the natural grasslands dilemma. Livestock Science 120, 158-162.

Gill, R.A., Jackson, R.B., 2000. Global patterns of root turnover for terrestrial ecosystems. The New Phytologist 147, 13-31.

Godde, C.M., de Boer, I.J., zu Ermgassen, E., Herrero, M., van Middelaar, C.E., Muller, A., Röös, E., Schader, C., Smith, P., van Zanten, H.H., 2020. Soil carbon sequestration in grazing systems: managing expectations. Climatic Change, 1-7.

IPCC, 2006. Agriculture, Forestry and Other Land Use. In: Eggleston, H., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.), 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IGES, Japan, p. 680.

IPCC, 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Jackson, R.B., Lajtha, K., Crow, S.E., Hugelius, G., Kramer, M.G., Piñeiro, G., 2017. The ecology of soil carbon: pools, vulnerabilities, and biotic and abiotic controls. Annual Review of Ecology, Evolution, and Systematics 48, 419-445.

Oesterheld, M., DiBella, C., Kerdiles, H., 1998. Relation between NOAA-AVHRR satellite data and stocking rate of rangelands. Ecological applications 8, 207-212.

Oliva, G., Ferrante, D., Puig, S., Williams, M., 2012. Sustainable sheep management using continuous grazing and variable stocking rates in Patagonia: a case study. The rangeland journal 34, 285-295.

Poeplau, C., Don, A., Vesterdal, L., Leifeld, J., Van Wesemael, B., Schumacher, J., Gensior, A., 2011. Temporal dynamics of soil organic carbon after land-use change in the temperate zone–carbon response functions as a model approach. Global change biology 17, 2415-2427.

Ricard, M., Viglizzo, E., 2020. Improving carbon sequestration estimation through accounting carbon stored in grassland soil. MethodsX 7, 100761.

Smith, P., 2014. Do grasslands act as a perpetual sink for carbon? Global change biology 20, 2708-2711.

Sokol, N.W., Bradford, M.A., 2019. Microbial formation of stable soil carbon is more efficient from belowground than aboveground input. Nature Geoscience 12, 46.

Stockmann, U., Adams, M.A., Crawford, J.W., Field, D.J., Henakaarchchi, N., Jenkins, M., Minasny, B., McBratney, A.B., Courcelles, V.d.R.d., Singh, K., Wheeler, I., Abbott, L., Angers, D.A., Baldock, J., Bird, M., Brookes, P.C., Chenu, C., Jastrow, J.D., Lal, R., Lehmann, J., O'Donnell, A.G., Parton, W.J., Whitehead, D., Zimmermann, M., 2013. The knowns, known unknowns and unknowns of sequestration of soil organic carbon. Agriculture, Ecosystems & Environment 164, 80-99.

Viglizzo, E., Ricard, M., Taboada, M., Vázquez-Amábile, G., 2019. Reassessing the role of grazing lands in carbon-balance estimations: Meta-analysis and review. Science of The Total Environment 661, 531-542.